algorithm for smoke production, many references are available that provide ratios and rates of combustion product development as a function of heat release rate.[27] A practical example of the use of predictive modeling is a study done for the Transuranium Processing Plant at Oak Ridge National Laboratory (ORNL).[28] This analysis was done to determine whether the final HEPA filters in the facilities off-gas ventilation system were at risk from fire in the hot cells. Due to the nature of the activities performed in the hot cell facilities, there is a justified potential for accumulation of flammable materials over longer-than-desirable periods of time. These facilities are well engineered and at times contain ignition sources. In addition, they are often protected by heat detector-activated water deluge sprinklers, and the shutdown procedures generally involve isolation of the cell and either termination or reduction of its air supply. Since the enclosure construction is necessarily massive for shielding purposes, heat losses for fires in the cell are very large. These factors combine to make hot cells and assorted caves inherently fire-resistant. Nonetheless, this analysis was prompted by the concerns of an independent consultant about the resident fire load in some cubical of this facility. The modeling predictions showed that the maximum credible fire would become oxygen-depleted before hazardous conditions could escape the cubical. In addition, the predicted equilibrium temperatures from these fires would be cooled to acceptably low temperatures by dilution and convective heat transfer along the ventilation circuit to the filter plenum.

Tests were later done using the LLNL fire test cell modified to simulate the cubical at ORNL. The tests confirmed the conditions predicted by the modeling study. The only difference in results between the physical tests and the mathematical modeling effort was that the overall cost of the tests program was ten times higher.[29]

10.5 FIRE PHENOMENA

This section is divided into segments discussing some of the phenomena associated with fires occurring outside the confinement ventilation systems, as well as within these systems. For each of these types of fires, the subject matter is further divided according to the matrix show in **TABLE 10.1**.

Fire is a complex phenomenon that involves the initiation of an event and subsequent actions that can mitigate or exacerbate the event's effects. The matrix in TABLE 10.1 first covers the initiation and generation of harmful products from a fire. Then the means by which these harmful effects are transported throughout the confinement ventilation system are discussed. Finally, the impacts of these harmful effects on the main components of the confinement ventilation system are discussed. The material in this section indicates the fire hazards that must be mitigated. The techniques for mitigation are presented in the next section.

TABLE 10.1 – Fire Phenomena Matrix

	Heat	**Smoke**	**Related Effects**
Generation	Fire growth	Initial Aerosol makeup	Water vapor, Chemical releases, deflagrations
Transport	Temps in ducts	Change in aerosol with time and temperature	Change with movement through ducts
Effects on Filters	Media failure	Filter Media plugging	Filter Media plugging and failure

10.5.1 FIRES OCCURRING OUTSIDE A CONFINEMENT VENTILATION SYSTEM

Fires occurring outside a confinement ventilation system generate combustion products that are drawn into the confinement ventilation system when it operates as intended. These combustion products will affect the components of the confinement ventilation system.

10.5.1.1 GENERATION OF HEAT, SMOKE, AND RELATED PRODUCTS

Thermal Effects From Fire Initiation and Growth

Issues concerning the events that initiate fires can be solved by examining the known history of things that have caused fires in nuclear facilities in the past and by designing systems to accepted standards. Where unknowns are found to exist, unique hazard and failure modes analyses can be performed to further address the situation and outline the risks of mitigation or acceptance.

The designer of nuclear air cleaning systems must accurately characterize the design basis fire. This fire must be chosen to be sufficiently conservative (i.e., severe) to be an upper bound for the mitigative features protecting the function of the confinement ventilation system.

Of particular importance to the continued function of a confinement ventilation system are the generation and characteristics of fire combustion products—hot gases, smoke, and water vapor.

Smoke Generation

Smoke contains particulates that can pose a significant "plugging" threat to HEPA filters.

Smoke is a visible suspension of solid and/or liquid particles in gases resulting from combustion and pyrolysis. Soot is intrinsically part of the definition of smoke. However the term "soot" can be further refined to mean finely divided particles, mainly carbon, produced and/or deposited during the incomplete combustion of organic materials. Moreover, the amount of smoke generated from any material is strongly influenced by the same conditions that effect combustion efficiency. In general, smoke is a heterogeneous combination of solid and liquid particles of varying size and composition. Their instantaneous character depends on the material of origin, combustion conditions, environment, and flow dynamics. The sizes of particulates vary from 0.002 to 0.5 ìm, depending on the experience described above. Conditions related to incomplete combustion generally result in aerosol distribution of larger mean particulate size. However, if the smoke concentration is high, particle agglomeration (smoke aging) proceeds rapidly, as does fallout and surface deposition.

Agglomerated smoke aerosols can attain diameters as large as 10 ìm in plumes from fires, however, visibility is most influenced by particulates with diameters of -1.0 ìm. Collections of data on smoke production rate (g of soot/g of material burned) are available that can be used to estimate visible obscuration and smoke detector response time.

Water Generation

The quantity of water generated in the fire is as important as the soot and other particulates. Water vapor can condense on the particulates in smoke, both increasing their average diameters and leading to increased agglomeration that results in overall larger particulates. Larger particulates lead to more rapid HEPA filter plugging.

As a result of the process of combustion of the solid and liquid materials found in a typical nuclear facility fire, such fires generate a large quantity of water, with a corresponding potential for greatly accelerated HEPA filter clogging with smoke aerosols. Although smoke aerosols can clog filters by themselves, the presence of condensed water greatly exacerbates the clogging. Previous studies of HEPA filter clogging with smoke aerosols and separate studies with water clogging have shown that smoke and water mixtures cause much more severe and rapid filter plugging than dry smoke particles alone. These analyses are a new finding and differ from previous analyses in that water plugging results from the combustion process rather than from separate processes. The temperature of the exhaust is an important part of this analysis because it determines the extent of water condensation.

The phenomenon of water generation from combustion that is described here is an extension of the processes described by Gottuk and Roby.[30] The notation used here also follows their work.

The typical confinement fire is ventilation-controlled, and thereby starved for sufficient air for efficient combustion. A parameter used to characterize the degree of air starvation is the equivalence ratio, ϕ, which is defined as the ratio of the mass of fuel to the mass of air. Values less than 1 imply excess air, and the fire is well ventilated. Values greater than 1 imply insufficient air, and the fire is ventilation limited.

For $\phi < 1$, the rate of water generated is

$$(dm/dt)_{H2O} = Y_{H2O}\,(dm/dt)_f = k_{H2O}\,(dm/dt)_f \quad (1)$$

where

$(dm/dt)_{H2O}$ is the rate of water generated, g/s

Y_{H2O} is the yield of water generated, mass of water per mass of fuel, g/g

$(dm/dt)_f$ is the rate of fuel burned, g/s

k_{H2O} is the theoretical maximum yield of water generated, mass of water per mass of fuel, g/g

For $\phi>1$, the rate of water generated is

$$(dm/dt)_{H2O}=Y_{H2O}(dm/dt)_f=k_{H2O}\ B_{H2O}\ r\ (dm/dt)_a \quad (2)$$

where

$(dm/dt)_a$ is the rate of air consumed in the combustion, g/s

B_{H2O} is an experimentally determined average yield coefficient for under-ventilated fires (Table 2-7.2 in Reference 30)

r is the stoichiometric fuel air ratio, g/g

Equations 1 and 2 were derived from Equations 4, 10, and 18a of Gottuk and Roby.[30]

It should be noted that:

$$r = \text{mass fuel/ mass air} = (dm/dt)_f / (dm/dt)_a \quad (3)$$

Thus, at stoichiometry, Equation 2 is converted to Equation 1.

The terms k_{H2O} and r are determined at stoichiometric conditions and are a function of the specific fuel being burned. A general equation for these terms has been derived based on the stoichiometric combustion of a generalized fuel given by

$C_aH_bO_cN_dCl_e$,

where the letters C, H, O, N, and Cl represent carbon, hydrogen, oxygen, nitrogen, and chlorine atoms. The relative number of each of the atoms is given by the subscript letters a, b, c, d, and e. This general formula represents all of the major types of fuels found in nuclear facilities. For specific compounds, some of the subscripts are 0, which indicates the specific element is not part of the compound. For example, the formula for polymethyl methacralate (PMMA) is $C_5H_8O_2$, while polyvinyl chloride (PVC) is $CH_{1.5}\ Cl_{0.5}$.

The generalized stoichiometric fuel air ratio and theoretical yield for water production are given by Equations 4 and 5 respectively.

$$r = \frac{12a + b + 16c + 14d + 35.5e}{137(a + b/4 - c/2 - e/4)} \quad (4)$$

$$k_{H2O} = \frac{9(b-e)}{12a + b + 16c + 14d + 35.5e} \quad (5)$$

The stoichiometric water production given by Equation 5 can also be computed from the rate of CO_2 production using Equation 6.

$$k_{H20} = \frac{0.2045\,(b-e)}{a}\ k_{CO2} \quad (6)$$

Equations 4 through 6 can be used in Equation 2 to derive the rate of water production in a ventilation controlled combustion.

Summary of The Generation of Products of Combustion for External Fires

Many methods exist to establish the thermal history of the gaseous and particulate products of combustion from a postulated fire (in most cases, the type of fire experienced in a nuclear facility would be a ventilation-controlled fire, rather than a fuel-controlled fire).

Once the mass of smoke and water generated for a given fire have been established, the temperature that occurs at the HEPA filter will determine how much of the water remains in the gaseous state or how much is condensed.

10.5.1.2 Transport of Heat, Smoke, and Related Products

Heat Loss in Ducts

Hot gas from fires may enter the exhaust duct system and lead to excessive temperature at the HEPA filters if not mitigated. The two primary tools for analyzing the cooling of hot exhaust gas are (1) dilution analysis with additional exhaust streams and (2) duct cooling by convective and radiative heat transport.

Alvares, et al.,[30] computed that, if gases entering a duct are "less than 1,000 degrees Fahrenheit, the heat transfer along the duct is sufficient to reduce the gas temperature at the final HEPA filter station to acceptable temperatures. For example, Alvares, et al.,[30] computed that 6,000 cfm of hot gas at 1,040 degrees Fahrenheit passing through 118 ft of 1.5-ft diameter duct will be cooled to 332 degrees Fahrenheit. He used Equation 3 for these computations:

$$\Delta T_{out} = \Delta T_{in}\ e^{-\frac{hA}{WC_p}}$$

where A = total outside duct area,

W=air mass flow rate (weight/time)

Cp=air-heat capacity

FIGURE 10.1 illustrates a different computation showing the very rapid cooling that can occur with a long section of ducting.

Smoke and Water Loss in Ducts

A large quantity of smoke and water will be removed in the ventilation ducts. Alvares, et al., found about 60 percent of the aerosol mass (including water) was lost between the duct entrance and the HEPA inlet (about 19 ft for a 2-ft x 2-ft cross-section duct).[31] Ballenger proposed an equation to describe the particle loss in ducts:

$$C_L = C_0\ e^{-\frac{4vL}{DV_g}}$$

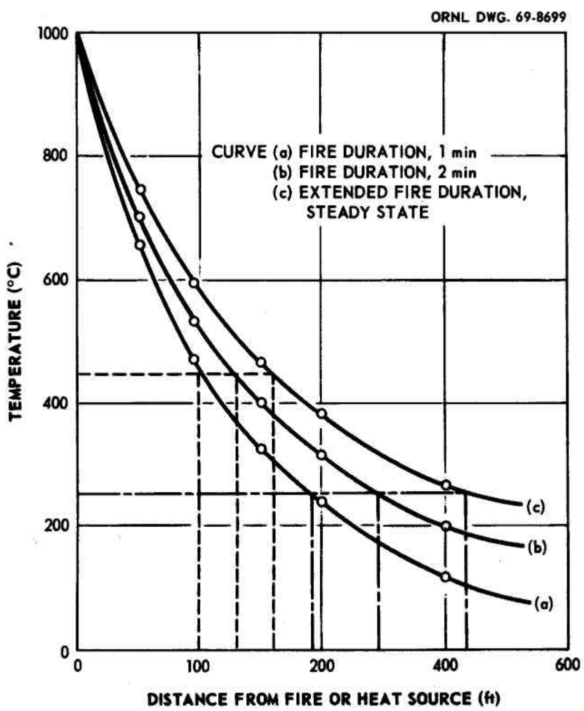

Figure 10.1 – Cooling rate of air in a 12-in-diameter duct carrying 1,000 cfm of air with inlet temperature of 1,000 degrees Celsius

where

C_0 is the concentration of smoke at the entrance of the duct.

C_L is the concentration of smoke at the end of the duct.

D is the duct diameter.

V_g is the flow velocity in the duct.

v is the drift velocity of particles toward the duct wall.

Equation 2 is a generic equation used to describe aerosol loss in ducts, electrostatic precipitators, etc., where there is a constant force driving particles from the streamlines.[21] This force could be gravity, electrostatic, thermal, and turbulence. For electrostatic precipitators, this equation is called the Deutsch Equation.

Since the determination of v is generally difficult and will vary from system to system, Equation 2 is typically used to fit the specific experimental data one wishes to model. For this example, Equation 2 and other equations will be used to estimate the reduction of smoke aerosols in the ducts.

Because confinement systems are part of the enclosures that support operations with nuclear materials, computer codes have been developed to predict the results of accidents on the internal conditions within the system. For fire events, the room fire models discussed above can serve as the source term for codes that treat the response of components within the containment ventilation system. The Fire Accident Analysis Code (FIRAC)[32] predicts nodal gas and surface temperature in an experimental ventilation network with good precision when using a defined heat source for a specified period.[55, 56] A collateral result of this research shows the effectiveness of heat losses from turbulent convection in uninsulated ducts. In these tests, heat loss for hot air flow through uninsulated metal ducts reduced gas temperature by a factor of 3 over 31.7 m of duct length. These results showed that HEPA filters at the final plenum of long ducts may have little risk of high temperature exposure. [Note that similar results were derived a decade earlier for nuclear ducts using simple heat exchanger theory.][33]

The other ventilation code for predicting fire effects in ventilation systems is SIMEVENT.

SIMEVENT uses the equilibrium temperature algorithm developed at LLNL as the fire source term. This relationship, along with an empirically derived filter clogging model, provides temperature and filter plugging predictions that are in reasonable agreement with experimental data from naturally burning test fires.[34] [Active research is in progress at France's ISPN to further the utility and applicability of the model for French nuclear industry design purposes.]

These codes can be used to predict the time and temperature profile in the confinement ventilation system ducts to establish the impact of the products of combustion on the various HEPA filter stages.

The transport of related products (e.g., chemical) can be modeled using available techniques. The form and dispersion characteristics of the chemical in question must be understood, and analysis methods for the entrainment and transport of chemicals are generally well understood in confined situations such as ducts. Once this is done, the effects on the HEPA filters can be shown with time.

10.5.1.3 Effects on Filters of Heat, Smoke, and Related Products

The impact of fires on the integrity of the final HEPA filters can be determined through a sequence of analyses to establish (1) the dynamics of the design basis fire; (2) the generation of smoke, water, and heat (temperature) that enters the confinement ventilation system; (3) the mitigation of smoke, water, and heat through the ducting to the final HEPA filters; and (4) the response of the final HEPA filters to the smoke, water, and heat that reach them. The interaction of smoke, water, and temperature play a major role in the plugging of HEPA filters, as well as the consequent rise in filter pressure drop and the possible reduction in exhaust flow. This sequence of analysis will determine the design basis fire's potential for causing structural damage to the final HEPA filters, thereby increasing the filter penetration. Finally, the impact of the smoke and water loading and the air temperature on the final HEPA filters must be determined.

HEPA Filter Response to Temperature

Since fire-resistant HEPA filters that meet the requirements of Underwriters Laboratory (UL)-586[35] and prefilters that meet the requirements of UL-900[36] are the recommended types in DOE nuclear facilities, this discussion concerns the effects of temperature upon those types only.[37,38] The fire-resistant HEPA filter in both steel- and wood-cased construction is designed to withstand air temperatures of 700 to 750 degrees Fahrenheit for at least 10 to 15 min without serious degradation of function, as long as airflow continues and the filters do not become plugged. There is, however, a rapid decrease in the tensile strength of the medium at about 450 degrees Fahrenheit; at temperatures above 800 degrees Fahrenheit, the fibers begin to break, curl up, and "pill," leaving pinholes in the medium.[39] Extended exposure to temperatures above 800 degrees Fahrenheit will cause destruction of the case of wood-cased filters and warping of the case of steel-cased filters, allowing unfiltered air to bypass the filter. Rapid deterioration of all but ceramic-sealed filters can be expected at temperatures above 1,200 degrees Fahrenheit. The medium of HEPA filters is thin (0.015 in.) and can be destroyed by incandescent sparks, flaming trash, or burning dust on its surface.

To be listed by UL under UL-586[35] as a HEPA filter unit, HEPA filters are required (1) to withstand 750 degrees Fahrenheit (402 degrees Celsius) air for 5 min at rated airflow capacity and have greater than 97 percent test aerosol efficiency, and (2) to withstand a spot-flame test in which a Bunsen burner flame is placed on the filter core with no after-burning when the flame is removed. However, it should be noted that there is a rapid decrease in the tensile strength of the filter media at about 450 degrees Fahrenheit (234 degrees Celsius), and when temperatures get above 800 degrees Fahrenheit (430 degrees Celsius), the fibers in the filters begin to break and curl up, leaving pinholes in the filter media. Extended exposure to temperatures above 800 degrees Fahrenheit (430 degrees Celsius) will cause destruction of the case in wood-cased filters and warping of the case in steel-cased filters, resulting in bypassing of unfiltered air.

Although HEPA filters can withstand a temperature of 750 degrees Fahrenheit (402 degrees Celsius) for a very limited time duration, they should not be subjected to indefinite exposure temperatures higher than 275 degrees Fahrenheit (136 degrees Celsius). Longer filter life and more reliable service, as well as a greater operational safety factor, can be obtained when normal operating temperatures are below 200 degrees Fahrenheit (94 degrees Celsius) and high temperature extremes are avoided.

Continuous operation of HEPA filters at higher temperatures is limited primarily by the filter sealant used to seal the filter core into the filter case. At higher temperatures, the sealants lose their strength, causing the filters to fail. For example, standard urethane seals are suitable for service at 250 degrees Fahrenheit (122 degrees Celsius), while some silicone seals can withstand 500 degrees Fahrenheit (262 degrees Celsius).

Because different sealants are available and different filter manufacturers rate their filters for different temperatures, the best practice for ventilation system designers and operators is to determine the manufacturer's limiting continuous service temperature if continuous operation at high temperatures is necessary.

HEPA Filter Response to Smoke and Water Loading

Water from combustion plays a major role in potential HEPA filter clogging with smoke aerosols. The temperature at the HEPA filter is important for determining the extent of water condensation from the fire exhaust. The HEPA filter-plugging studies suggest using the following approach to analyze the potential of fires to plug HEPA filters.

The design basis fire and its combustion products having been previously established, transport of the hot gases, smoke particulates, and water vapor through the duct system are established. The characteristics of the combustion products penetrating the prefilter or demister are determined next. This process will yield a mass of smoke aerosols for comparison to a reference mass holding capacity for HEPA filters. The amount of water condensing on the smoke deposits is determined from the temperature at the HEPA filters and from the combustion water loading.

The nature of the aerosols has a major effect on plugging of all filters, including deep-bed sand (DBS) filters, prefilters, and HEPA filters. Previous studies have shown that, in addition to the mass of the smoke aerosols, the particle size and the state of the aerosol (liquid or solid) significantly affect HEPA filter clogging.

Figure 10.2 and Table 10.2 illustrate some of the effects of particulates on HEPA filters.

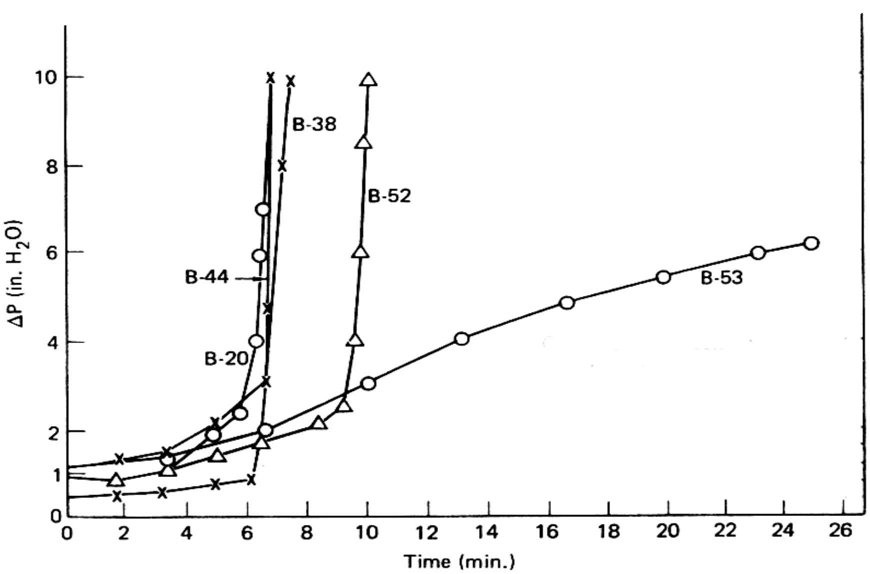

Figure 10.2 – Aerosol loading of HEPA filters by smoke from composite cribs for the different conditions shown in TABLE 2 (composite cribs consist of 40 percent wood, 14 percent PVC, 29 percent FRP, 9 percent PMMA, and 8 percent polycarbonate). [40]

Table 10.2 – Test Conditions for the HEPA plugging Measurements in Figure 10.14[40]

Test	HEPA Size (cfm)	Exhaust Flow (cfm)	Fuel Burn Rate (g/min)	Smoke Concentration (g/m3)	Temp at HEPA (degrees Celsius)	HEPA wt. Gain (g)
B-44	1,000	500	3,000	6.4	65	470
B-20	500	500	1,200	4.8	86	--
B-38	500	1,000	3,000	8.6	105	574
B-52 (free burn)	500	500	1,500	7.6	70	106
B-53	500	1,000	1,680	8.4	110	550

In related tests using rolling prefilters (the media roll advances through the test duct as it plugs), Bergman, et al., showed that, once a fire and the ventilation system have reached the point where the smoke generated can plug a HEPA filter, plugging can occur within 1 min, as seen in **FIGURE 10.3**. **Tests 2 through 5** showed that the prefilters were not effective in protecting the HEPA filter from plugging until the prefilter efficiency had a minimum efficiency of 90 percent for milli-micron particles. **FIGURE 10.4** shows the efficiency for the different filter media used in the tests in FIGURE 10.3. Test 5, with insufficient media replacement in the roll, illustrates how rapidly the HEPA filter plugs when exposed directly to the proper aerosols. The plugging potential of the smoke aerosols is so great that it dominates all other parameters.

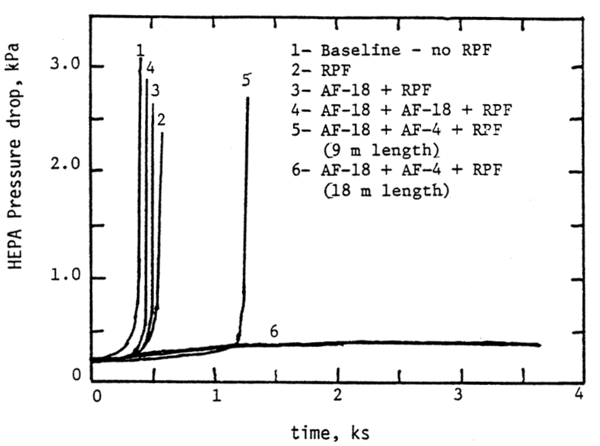

Figure 10.3 – HEPA Filter plugging by smoke aerosols with various rolling prefilters. [7]

FIGURE 10.5 shows an electron micrograph of the aerosols generated from composite burns. The deposits show the smoke aerosols were liquid because of the drop-like spheroid coating the fibers. The deposits have solidified because any liquid would not have remained in the high vacuum of the scanning electron microscope. Filter plugging with solid aerosols, as shown in **FIGURE 10.6**, does not show the same rapid increase in pressure drop as the liquid aerosols.[41]

Prior Filter Exposure That Impacts Filter Response

Water Exposure

Water is an effective method for reducing temperature, but HEPA filters are not designed to operate when wet and may suffer structural damage. Unlike qualification tests for some other fire-resistant materials, the test standards used to qualify HEPA filter media do not require multiple wettings. In fact, the media is permitted to lose up to 50 percent of its strength after a single 15-min soaking period. There is no requirement for the media to return to full strength after drying and no limitation on further reduction in strength after subsequent soakings. Testing of both new and used filters verifies that they lose strength after thorough soaking and that subsequent soaking may produce further incremental reductions in strength. **FIGURES 10.7 THROUGH 10.8** further illustrate the

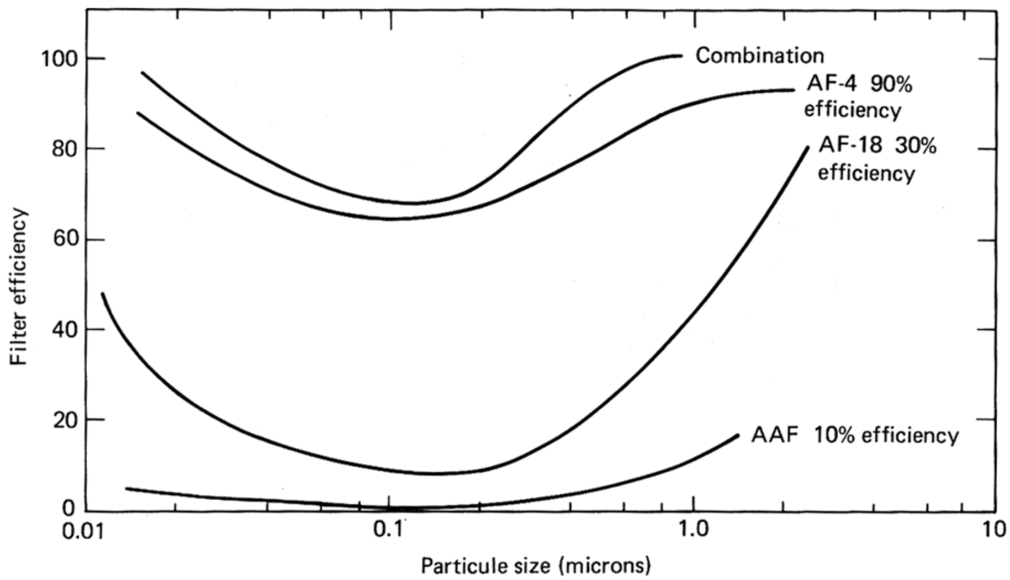

Figure 10.4 – Efficiency of different layers of prefilters as a function of particle size. Efficiency values refer to the ASHRAE Dust Spot efficiency. [40]

relationships between particulates, temperature, and water-saturated air.

Filter Age

Bergman[42] has shown that aged filters become structurally weak and can fail with less stress than newer filters. He also showed that, if HEPA filters are replaced within 5 years in wet applications and within 10 years in dry applications, they will show no additional degradation due to age.

Chemical Exposure

The exhaust from chemical treatment systems may contain trace chemicals that may impact the performance of HEPA filters

Bergman, et al.,[7] and the USNRC described the factors that can cause structural damage and, consequently, a deterioration of filter efficiency. These factors include high temperatures, smoke clogging, water exposure, and chemical attack.[44,45] The effects of chemical exposure on filter media have to be analyzed for each unique case.

Other Filter Types

Not all filter types are as subject to the thermal and combustibility effects as are typical HEPA filters with combustible media. Plugging from smoke particulates can be a concern for all types of filters, however.

Figure 10.5 – Scanning electron micrograph of HEPA filter media loaded with smoke aerosols from composite crib fires. Note the drop-like globules attached to the filter fibers that suggest the liquid nature of the aerosols. [40]

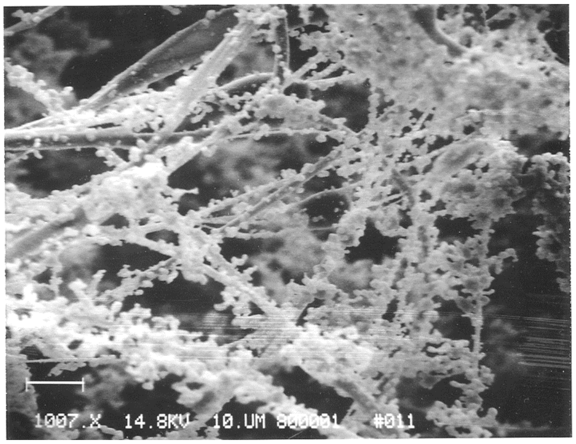

Figure 10.6 – Scanning electron micrograph of sodium chloride aerosols on glass fiber prefilter. [41]

10.5.1.4 Effects To Physical Integrity of the Confinement Ventilation System Components

Fires occurring external to the confinement ventilation system may not only have damaging effects to the HEPA filters inside the confinement ventilation system, they also may damage to integrity of the confinement ventilation system ductwork and enclosures. If the confinement ventilation system ductwork or enclosures are breached, some or all of the functionality of the confinement ventilation system will be impaired. This must be considered in the design of the physical components and the fire suppression systems provided in the facility.

10.5.1.5 Effects of Wildland Fires

As the Cerro Grande fire in Los Alamos in 2001 demonstrated, smoke from wildland fires can cause significant problems for confinement ventilation systems. The smoke will plug filters just as easily as smoke from a facility fire. Facilities in areas where this type of event may occur should consider this in the design and operation of their facility.

10.5.2 Fires Occurring within Confinement Ventilation Systems

Fire may originate from sources within the confinement ventilation system (generally speaking, glovebox-sized operations and small hot-cells). Room-sized fire events fall into the category of external fires for the purposes of this handbook. Their effects, although similar to those resulting from fires external to the confinement ventilation system, may be different and require different controls.

Radioactive materials are refined, fabricated, analyzed, converted, stored, and handled in a wide range of operational facilities, including laboratories, industrial facilities, hospitals, and

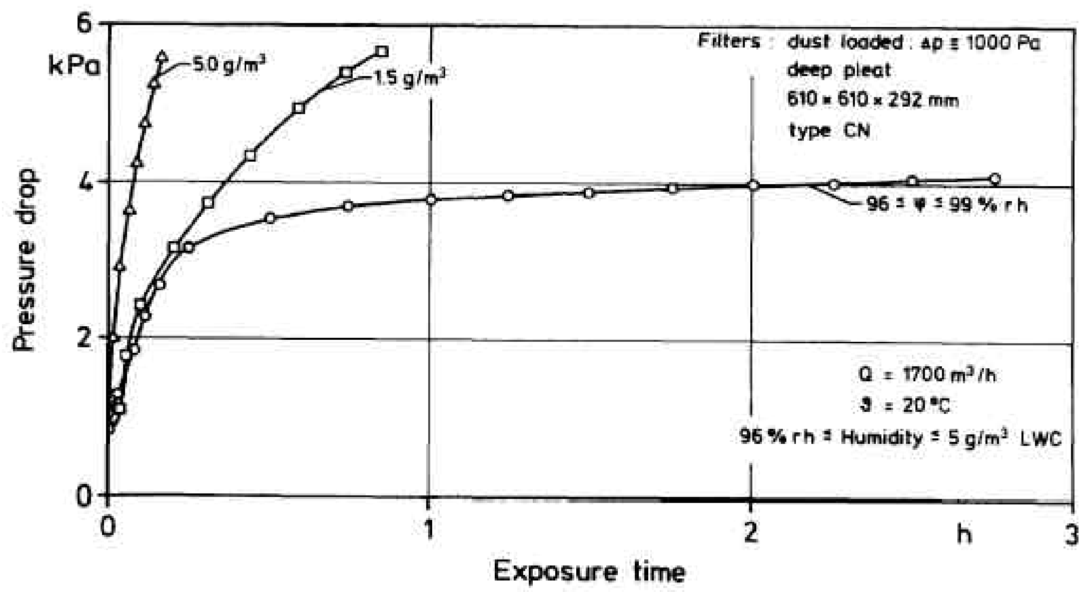

Figure 10.7 – Illustration of rapid pressure drop increase with water saturated air. (Ricketts et al.) [43]

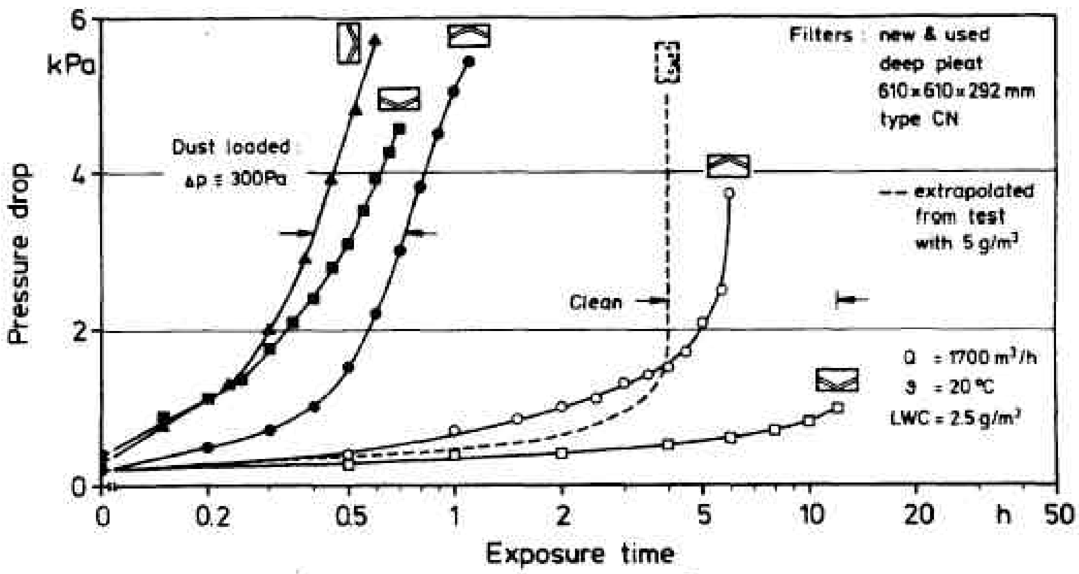

Figure 10.8 – Rapid filter plugging due to moisture deposition on particle-loaded HEPA filters [43]

schools. Because radioactive materials have varying degrees of hazard potential, they require special handling in special enclosures. These enclosures can range from simple hoods with negative exhaust capabilities to small hot cells (caves) of very robust construction that are designed for limited, specific, hazardous operations. Included within this range of enclosures are nuclear workrooms, gloveboxes, production lines, conveyer lines, pass-through boxes, and wells. (i.e., operational enclosures where work is done).

The internal environment is generally circulated air drawn from the surrounding facility and exhausted through HEPA filters that collect aerosols generated during operations. In some cases, the enclosure may be isolated where the internal environment is an inert gas. Glovebox or hot cell enclosures can be individually ventilated or, as operations require, they may be interconnected. In ventilated enclosures (confinement structures), the air pressure gradient is always designed to be lowest where materials of highest toxic potential are worked with or stored. This design ensures that toxic materials will be contained so long as the ventilation system is operating. **FIGURE 10.9** is a schematic of a facility ventilation system where supply air for the glovebox is obtained from the laboratory, which in this case is the first stage of the confinement system.[37] At the simplest level, this schematic contains all of the components of a generic confinement ventilation system, regardless of the confinement appliance or operation. Missing from the schematic are any examples of the facility fire management system, as well as any fire protection measures for the confinement ventilation system indicated. It is reasonably expected that situations will temporally arise where combustible materials can accumulate in areas housing confinement systems. This can occur at times when modifications or changes in operational conditions are in progress. Materials that would normally be appropriately secured could be temporarily stored in passageways or unauthorized spaces. Common items that could be stored in such places include furnishings, finishes, computers, diagnostic equipment, electrical and thermal insulation, cellulosic materials, fabrics, elastomeric gloves, solvents, plastic materials, paints, and oils.

10.5.2.1 GENERATION OF HEAT, SMOKE, AND RELATED PRODUCTS

Fire events occurring inside a confinement ventilation system may appear in a number of physical forms. Fire may occur in ordinary combustible material. The amount of combustible material within a confinement ventilation system generally would not be as much as in a larger room, so the fire growth characteristics may be altered somewhat. Techniques for analyzing fire in small compartments exist and are thus not presented here.

Fire may occur in the radioactive materials in a confinement ventilation system, or a fire involving ordinary combustibles may subsequently involve radioactive materials. A fire also may occur that involves a flammable liquid or gas used inside a confinement ventilation system. These events may take the form of a flame front moving rapidly through a flammable vapor, a flame front moving rapidly enough to deflagrate and produce some overpressure, or even a situation involving a detonation if the conditions for such a phenomena exist.

Filter fires can occur due to either decomposition of combustible dust deposits within the filter, organic decomposition of chemical residue carried by the air stream from upstream processes, or spark/ember introduction from an upstream source. While the latter condition can be prevented by introducing a high-speed water spray or water mist arrangement within or prior to the duct inlet, fires originating at the filter itself cannot be satisfactorily mitigated by automatic suppression methods. Industrial and institutional loss experience has shown that, over time, even "office dust" accumulations can form highly combustible residues on filters that are sufficient to cause damage. It has also been established that the concentration of these fuels need not be high to cause severe damage due to the fragility of the media. Fire-retardant chemical preparations for the filter media may initially make ignition difficult, particularly on clean media. However, this retardant material tends to become less effective over time and does nothing to retard or reduce the combustibility of dust or residue deposits from the air stream itself.

While administrative controls and alarm interlocks are designed to alert operators about impending change-out intervals that have been established to maintain dust or residue inventories below radiological actions points, it is not feasible to eliminate the potential for direct filter fires or to practically reduce residue levels below those that may damage the filter itself.

10.5.2.2 TRANSPORT OF HEAT, SMOKE, AND RELATED PRODUCTS

The transport of hot gases, smoke, and water vapor, and chemicals through a confinement ventilation system from an internal fire can be modeled in much the same way as from an external fire. A fire occurring internally to the confinement ventilation system may affect the transport mechanism by altering the airflow through the confinement ventilation system more so than an external fire.

The transport mechanism also may be affected if the actual structural confinement barrier of the confinement ventilation system, which may be a polymeric material, is involved in the fire and contributing to its spread. The accumulation of dust and debris inside the air cleaning system ductwork over long periods of operation increases the consequences of the fires that might occur.

10.5.2.3 EFFECTS ON FILTERS OF HEAT, SMOKE, AND RELATED PRODUCTS

The effects of the products of combustion reaching the HEPA filters are the same for internal and external fires. The same physical parameters affect the manner in which the filters are threatened.

10.6 FIRE HAZARD CONTROLS AND DESIGN FEATURES

10.6.1 OBJECTIVES AND REQUIREMENTS

There are two major objectives for fire protection of confinement ventilation system:

- To prevent fires from affecting the operation of the ventilation system
- To protect the filtration function

General requirements for the control of fire hazards that may affect the confinement ventilation system are formalized in NFPA standards 801[46], 802[47] and 803[10] and DOE Orders 420.1[23] and 440.1A.[49] NFPA 801[46] delineates problems and fire protection solutions that are specific to hospitals, fuel fabrication facilities, fuel reprocessing facilities, laboratories, gloveboxes, hot cells, hoods and caves, and ovens and furnaces. In NFPA 802,[47] considerations related to fire risk and fire protection procedures are